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The effect of the input load current changed to a 1.2 kW PEMFC performance

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Abstract

This paper focuses on the performance and dynamic behavior of proton exchange membrane fuel cell (PEMFC) with 1.2 kW under varies of an input load current. The mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. The some parameters in the model are kept constant. The performance and dynamic behaviors of PEMFC are determined by applied the variety of input load current with different types of input load current, such as saw-tooth, step, step input with dead time, and multi-step input load current. The results of model are compared to the experimental results. The results of the model show that the output cell voltages are suddenly dropped when the input load current have been increased and output cell voltage increased when decreased the input load current. This mathematical model can predict the dynamic behavior of the PEMFC when the input load currents have been changed. The experimental setups use 1.2 kW of PEMFC with connected to electronic load device and can be operated the input load current from 0A to 500A. Hydrogen is used as a fuel at the anode side and air is used at the cathode side. The operating temperature is kept to be constant at room temperature. The experiments show that the output cell voltage is decreased when the input load current increased. There is some slightly different between the model and experiment results when compared at the same conditions. This is because of in the model we kept some parameter constant. The water generated during the process is tested under varying input load current from 1A to 30A. The dynamic behavior of the PEMFC under different types of input load current shows very well.

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Keywords: Load current; PEMFC; Performance; Model of PEMFC; Dynamic behavior

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1. Introduction

Proton Exchange Membrane Fuel Cell (PEMFC) is an electrochemical energy converter that converts chemical energy of fuel directly into DC electricity. PEMFC uses hydrogen and oxygen or hydrogen and air as a fuel which feed into anode and cathode side of fuel cell as shown in Fig. 1

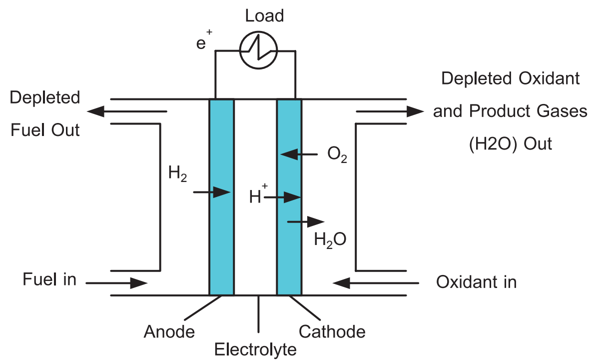

Fig. 1. Schematic diagram of a PEMFC [10].

PEMFC is constructed from a proton conducting polymer electrolyte membrane, usually a perfluorinated sulfonic acid polymer [2,4]. The chemical reactions producing at the oxidation and reduction electrode of a PEMFC are shown in Eqs.*(1)* and *(2) ;*

Anode: $$H_2 \rightleftharpoons 2\,H^+ + 2\,e^- \quad (1)$$

Cathode: $$(1/2)\,O_2 + 2\,H^+ + 2\,e^- \rightleftharpoons H_2O \quad (2)$$

Many researches and development of PEMFC have received much attention [1-10]. Some of them are pointed on mathematical model to study some of parameters that effected to both single and stack cells [3], [5-9]. Performance testing and application of PEMFC are evaluated in order to get optimize operation [1]. A phenomenon occurs inside fuel cell is very difficult to predict. Also, parameters that effected to PEM fuel cell performance are very hard to indicate. In order to understand the behavior and characteristics of PEMFC performance, the mathematical model is developed.

A mathematical model of PEM fuel cell is presented. Performance of PEM fuel cell is studied by changing some parameters in order to show the behavior and characteristics under various operation conditions. The objectives of this research are to study parametric which affect to PEMFC performance and develop the PEMFC model under various operation conditions by changing the input load currents.

Nomenclature

V	real output voltage of fuel cell
E_{thermo}	thermodynamically predicted fuel cell voltage output
ΔE_{act}	activation loss due to reaction kinetics
ΔE_{ohmic}	ohmic loss from ionic and electronic condition

ΔE_{conc}	concentration loss due to mass transport
E^0_{thermo}	standard electrode potential
R	gas constant (8.3144 J/mol K)
T	temperature in Kelvin scale
n	number of electrons per reacting ion or molecule
F	Faraday's constant (96,500 C/mol)
p_{H_2O}	partial pressure of water
p_{H_2}	partial pressure of hydrogen
p_{O_2}	partial pressure of oxygen
α	activity coefficient
i_{loss}	current loss
i_O	exchange current density for reaction with constant value
I	applied current density
R_{ohmic}	resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell component
i_L	limiting current density with constant value

2. Theory and research methodology

A mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. Some of parametric have been studied to evaluate the effect of a PEMFC system performance. The PEMFC performance can be expressed *i-v* curve, which is shown in Fig. 2. The characteristic of this curve depends on output voltage and current density, which varies with parameters as shown in physical equations.

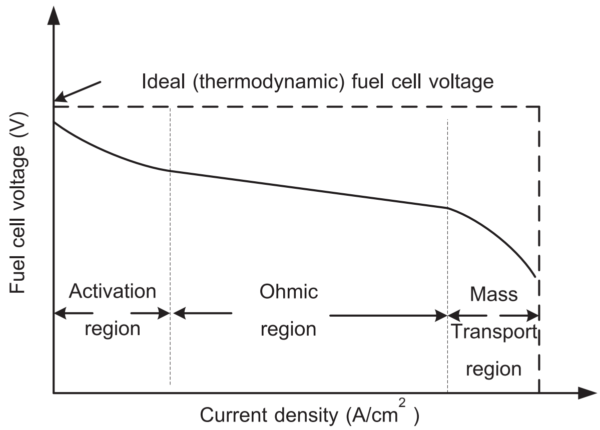

Fig. 2. *i-v* curve of PEMFC [10].

The output voltage of developing fuel cell is less than thermodynamically predicted voltage output due to irreversible losses. There are three major types of fuel cell loss, which occurred in fuel cell as follow: Activation losses are loss due to electrochemical reaction mostly affected in initial part of curve. Ohmic losses occur due to ionic electronic condition mostly apparent in the middle section of the curve. Concentration are losses due to mass transport was most significant in the tail of *i-v* curve. Each contains parameters, which depend on the physical dimensions of PEMFC. The output voltage of PEMFC can be written as Eq. *(3)* [2,4].

$$V = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \tag{3}$$

The output voltage of PEMFC depends on parameters that contain in three major losses which can be expressed in Eq. *(4)* through Eq. *(7)*. The result of chemical reactions inside a fuel cell is reversible single electrode potential, E_{thermo}, given by the Nernst equation as shown in Eq. *(4)*.

$$E_{thermo} = E^{0}_{thermo} - \left[\left(\frac{RT}{nF}\right) ln\left(\frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}}\right)\right] \tag{4}$$

The activation losses are due to reaction kinetics at the electrodes of a PEMFC is shown in Eq. *(5)*. This equation is commonly known as Tafel equation.

$$\Delta E_{act} = \left(\frac{RT}{\alpha F}\right) ln\left(\frac{i + i_{loss}}{i_o}\right) \tag{5}$$

Ohmic resistant losses, (R_{ohmic}) which includes ionic, electronic, and contact resistance, Ωcm^2, can be calculated from current density as.

$$\Delta E_{ohmic} = i\left(R_{ohmic}\right) \tag{6}$$

$$\Delta E_{conc} = \left(\frac{RT}{nF}\right) ln\left(\frac{i_L}{i_L - i}\right) \tag{7}$$

The parameters, such as i_o , α , T, and i_L, are studied to determine the effect of PEMFC performance.

3. Simulation results

The simulation results shown in Fig.3. There are activation losses due to an exchange current density (i_o) of the 1.2 kW PEMFC, when the i_o was increased by 10 times causing the output cell voltage decrease about 12%.

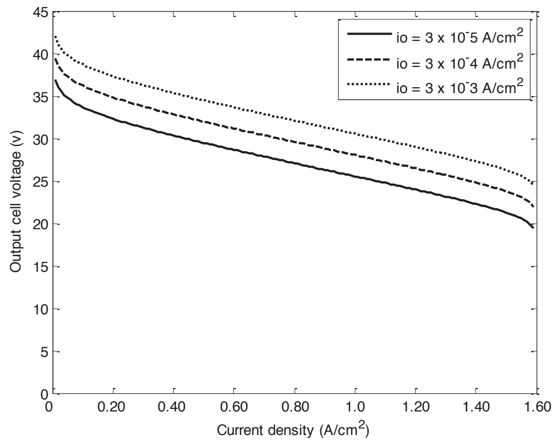

Fig. 3. The variation of exchange current density (i_o)..

Figure 4 shows the effect of vary the activity coefficient (α) by increase its from 0.5 to 0.9. The result of changing will cause the FC performance improved by 12% as shown in Fig. 4.

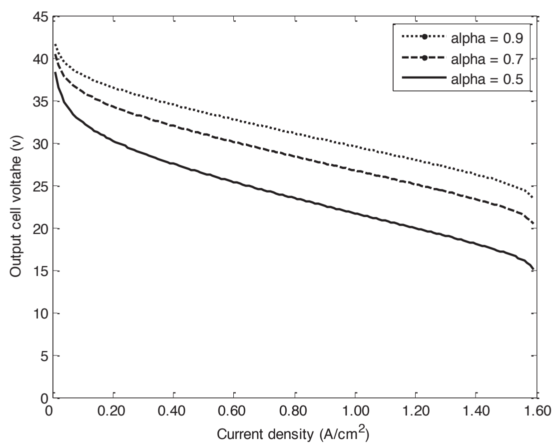

Fig. 4. The variation of activity coefficient.

Figure 5 shows the ohmic losses which are caused by resistance of ions flow in the electrolyte and resistance of flow of electrons through the electrically conductive fuel cell components. The increasing of ohmic loss by 33% will cause the FC performance decreased about 12%. Figure 6 shows the effect of limiting current density, i_L to the FC performance. Increasing of i_L by 6% will effect to FC performance decrease about 5% .

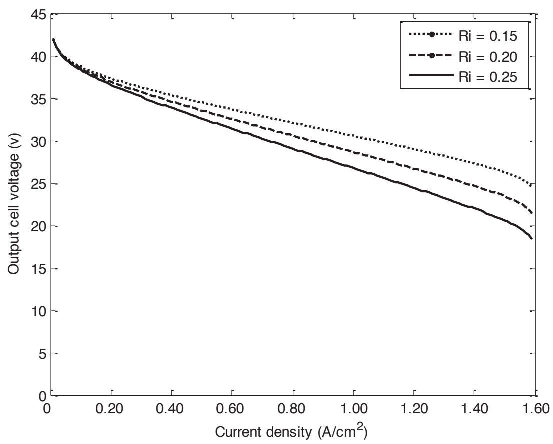

Fig. 5. The variation of resistance of ions flow in the electrolyte and resistance of the flow of electrons.

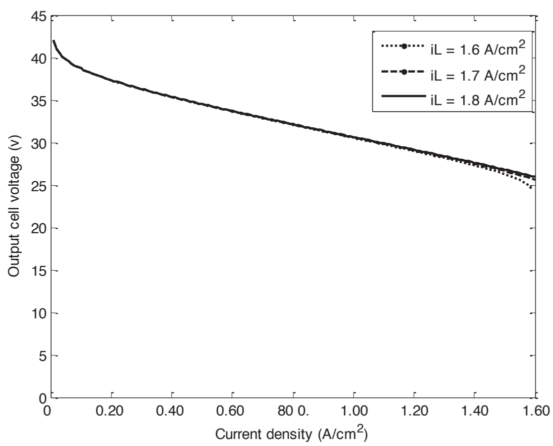

Fig. 6. The variation of the limiting current density in fuel cell.

Figure 7 shows the result of stack cell output voltage when the input load currents have been changed with step shape from 27A to 40A. It caused the output voltage of the PEMFC dropped as shown in Fig 7.

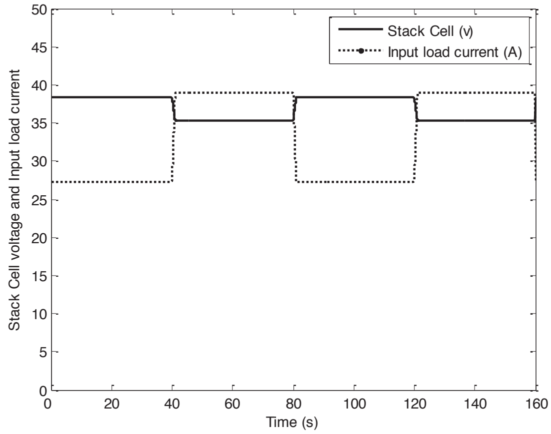

Fig. 7. Output voltage and current responses of step shape of input load current.

Figure 8 shows the output voltage and current responses of saw tooth shape of input load current. The input load current is slowly increased. It caused the output voltage of PEMFC gradually dropped and then, suddenly decreased the input load current caused the output voltage sharply increased. Figure 9 shows the output voltage and current responses of step shape of input load current with dead time.

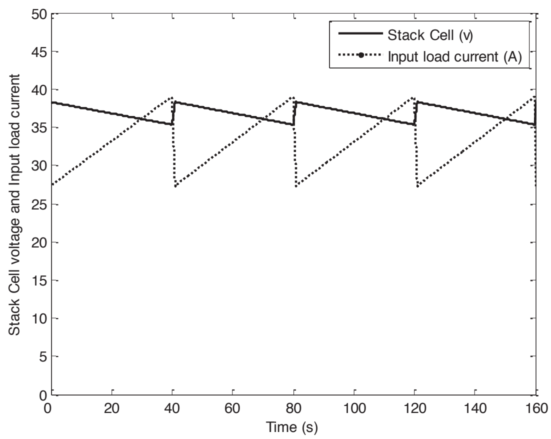

Fig. 8. Output voltage and current responses of saw tooth shape of input load current.

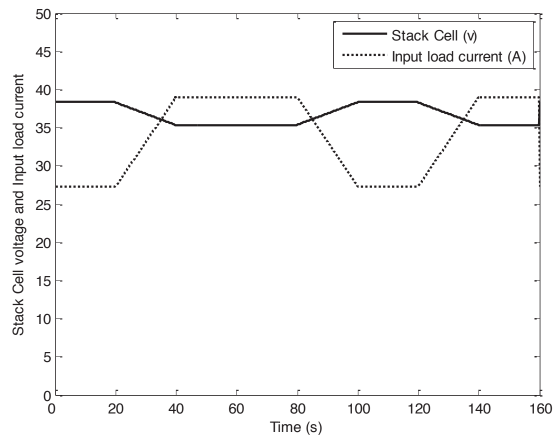

Fig. 9. Output voltage and current responses of step shape of input load current with dead time.

Figure 10 shows the output voltage and current responses of multi-step shape of input load current. The input load current is gradually increased caused the output voltage slowly decreased and then, increased the input load current suddenly. It caused the output voltage dropped.

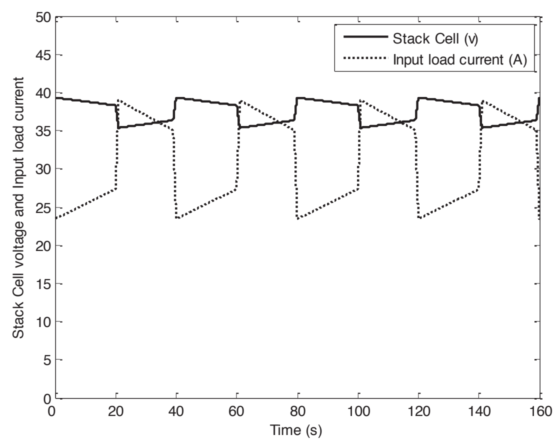

Fig. 10. Output voltage and current responses of multi-step shape of input load current.

Figure 11 shows the experimental devices, which consist of (1) Hydrogen tank (2) 1.2 kW PEMFC (3) Personal computer, and (4) Electronic load.

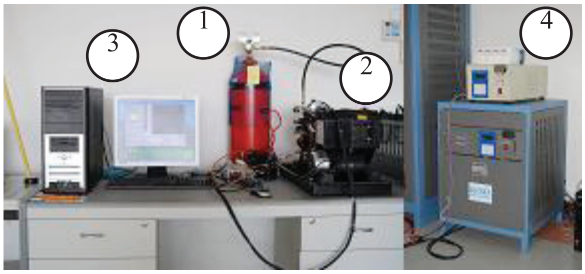

Fig. 11. Experimental device.

Figure 12 and 13 show the comparison of an experimental and model results of 1.2 kW PEMFC. Figure 12 shows the output voltage changed when the input load current has been changed from 1A to 5A with step shape. The result of both simulation and experiment results have the same trend but, there are some small different of the value during the input load current changed. The model result shows more rapidly changed when the input load current has been changed than the experiment result. Figure 13 shows the output voltage of both results under the changing of input load current from 5A to 30A. The simulation result shows the smooth line of decreasing and increasing of the output voltage when the input load current changed. In the other hand, the experimental result shows the output voltage decreased and increased as a ladder shape. Because the electronic load cannot be controlled smoothly to increase and decrease input load current.

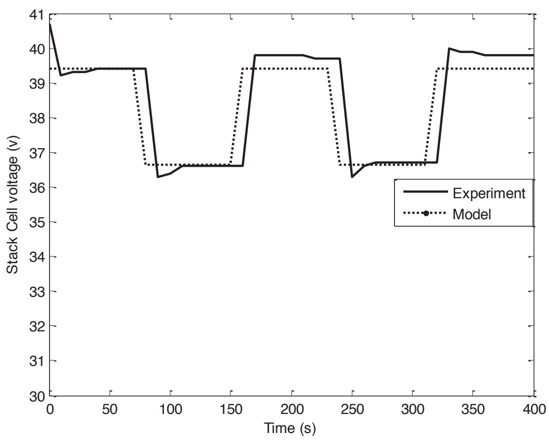

Fig. 12. The comparison of experiment and model results with step shape.

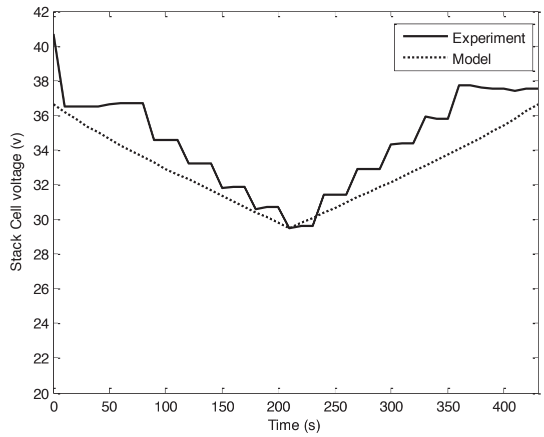

Fig. 13. The comparison of experiment and model results with triangle shape.

4. Conclusion

The mathematical model of the proton exchange membrane fuel cell (PEMFC) system is presented. The model is defined by parametrical equations that can predict the performance of fuel cell under various operations. The model results show some parameters affected to fuel cell performance. The input load current also affected to output voltage of fuel cell. The increasing and decreasing of input load current directly affected to the behaviour of fuel cell. The model has been validated to an experiment of 1.2 kW PEMFC. The model was developed in this paper. It can be used to study the behaviour of PEMFC under various operations. The input load current affected to PEMFC performance and performed characteristic behaviour of output voltage with different shape of input load current changed. This model can be also performing a detailed analysis of the effect of the PEMFC system using the developed model.

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